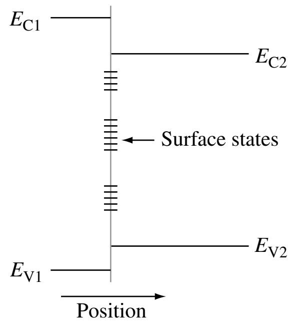

Figure 3.10 Illustration of surface states at a semiconductor surface or interface between dissimilar materials such as two different semiconductors (heterojunction) or a metal and a semiconductor (Schottky contact)

3.2.7 Carrier Transport

As has already been established, electrons and holes in a semiconductor behave much like a free particle of the same electronic charge with effective masses of m_n^* and m_p^*, respectively. Thus, they are subject to the classical processes of drift and diffusion. Drift is a charged particle's response to an applied electric field. When an electric field is applied across a uniformly doped semiconductor, the bands bend upward in the direction of the applied electric field. Electrons in the conduction band, being negatively charged, move in the opposite direction of the applied field and holes in the valence band, being positively charged, move in the same direction of the applied field (Figure 3.11) – in other words, electrons *sink* and holes *float*. This is a useful conceptual tool for analyzing the motion of holes and electrons in semiconductor devices. With nothing to impede their motion, the holes and electrons would continue to accelerate without bound. However, the semiconductor crystal is full of objects with which the carriers collide and are scattered. These objects include the component atoms of the crystal, dopant ions, crystal defects, and even other electrons and holes. On a microscopic scale, their motion is much like that of a ball in pinball machine, the carriers are constantly bouncing (scattering) off objects in the crystal, but generally moving in the direction prescribed by the applied electric field, $\vec{E} = -\nabla\phi$, where ϕ is the electrostatic potential. The net effect is that the carriers appear to move, on a macroscopic scale, at a constant velocity, v_{d}, the drift velocity. The drift velocity is directly proportional to the electric field

$$|\vec{v}_d| = |\mu\vec{E}| = |\mu\nabla\phi| \tag{3.52}$$

where μ is the carrier mobility. The carrier mobility is generally independent of the electric field strength unless the field is very strong, a situation not typically encountered in solar cells. The drift current densities for holes and electrons can be written as

$$\vec{J}_p^{\mathrm{drift}} = qp\vec{v}_{\mathrm{d},p} = q\mu_p p\vec{E} = -q\mu_p p\nabla\phi \tag{3.53}$$

and

$$\vec{J}_n^{\mathrm{drift}} = -qn\vec{v}_{\mathrm{d},n} = q\mu_n n\vec{E} = -q\mu_n n\nabla\phi. \tag{3.54}$$